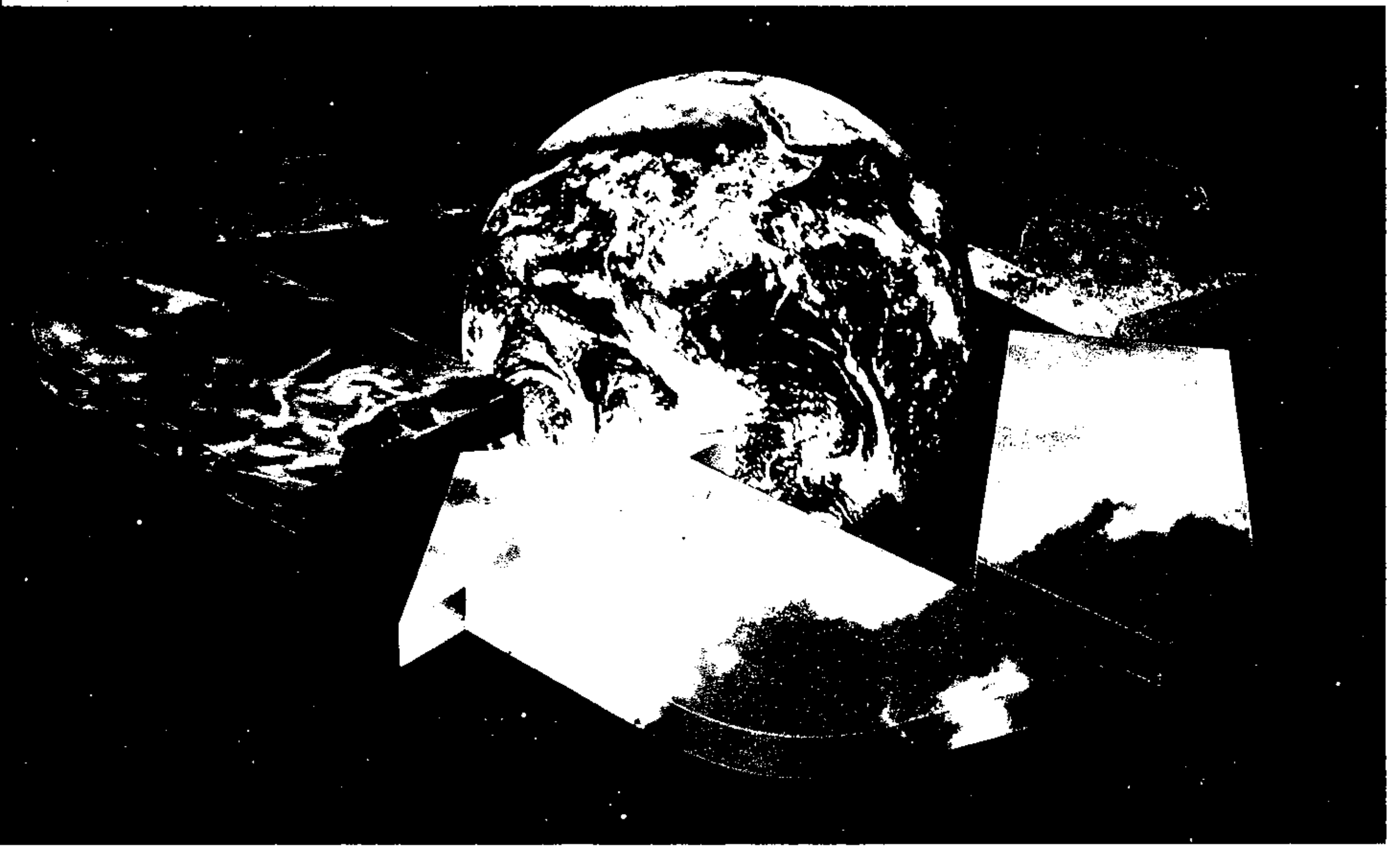
Report for

Thermostore



Thermostore

Reduction of Exhaust Emissions with a Heat Storage Tests on a Ford Taurus FFV

Ecotraffic R&D AB
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TABLE OF CONTENTS

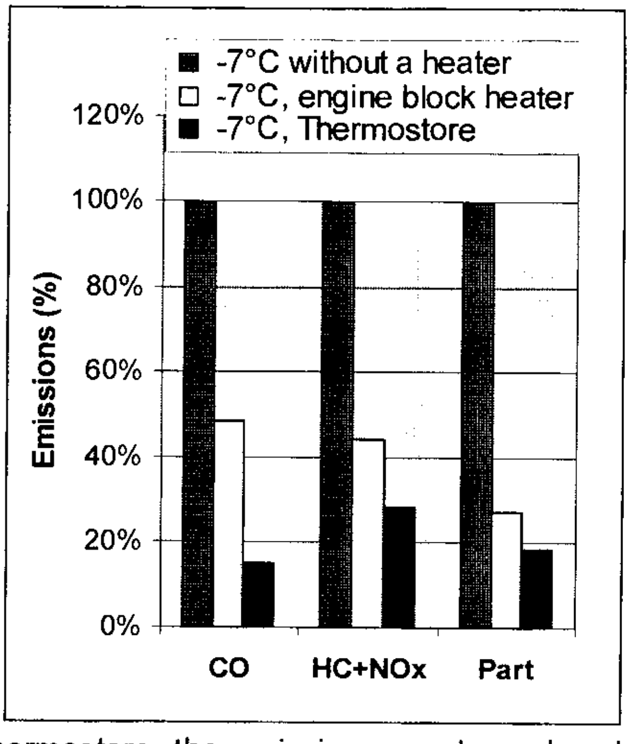
LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The exhaust emissions from on-road vehicles has been reduced considerably during the last years, mainly due to the introduction of the three way catalyst (TWC) on passenger cars. Further reductions are however, necessary to achieve a level tolerable for nature and humans. One problem with the TWC technology is that 80 % or more of the emissions in a driving cycle are generated during the cold start phase. Due to the cold climate in Sweden this problem is accentuated in the cold start phase. A heat storage has a great potential to considerably reduce these emissions.

A Thermostore heat storage has been tested to investigate it's emission reduction capabilities on a Ford Taurus FFV car. As a reference, an electric engine block heater has been tested as well. In the Figure to the right some of the results are shown.



Thermostore considerably reduces the CO, HC and particulate emissions at cold start. At an ambient temperature of –7°C the reduction can be as great as about 80 %. The reduction of the compounds that pose health hazards will most likely be *greater* than the reduction of the HC and particulate emissions. The NO_X emissions increase with Thermostore, but since these emissions were so low for this car the increase is not of concern.

By using the best control strategy for Thermostore, the emissions can be reduced even more than with a conventional engine block heater. There is also a potential for further reductions by using a more advanced control strategy. It must also be stressed that that a block heater cannot be used at every start and thus the emission reduction by using Thermostore will be much greater in practice. Another advantage is that a heat storage has no need for an external supply of energy and therefore has a considerably lower total energy consumption than a block heater.

Some initial tests, that are very promising, have been conducted on a Mercedes E 200, as well. The addition of further tests with simultaneous logging of emissions and temperatures will complete this test series. The objective of these tests is to obtain a better understanding of how the heat storage works. Thermostore will publish a report with these results later this spring. These results will be used in the future development of the product.

1 INTRODUCTION

The exhaust emissions from passenger cars in Sweden increased considerably from World War 2 to 1990 due to the increase in traffic intensity [1 – 6][1]. The emission regulations introduced in the 1970-ies reduced the rate of increase but these measures were not sufficient to reverse this trend. It was only after the introduction of the emission regulations that more or less demanded the three-way catalyst (TWC) emission control[2] that the emissions started to decrease. This regulation was introduced first in Sweden in 1987 as a voluntary measure, promoted by tax incentives, and was made mandatory for all cars after the model year 1989.

The catalytic emission control is very efficient – it can reduce the emissions by much more than 90 % on a warm engine at constant speed. However, during cold start the TWC technology is not operating at all, which yields very high emissions under these driving conditions. Due to the design constraints of the gasoline engine, fuel enrichment is needed at start to ensure that a sufficient amount of fuel can be evaporated and premixed (air-fuel preparation) to an ignitable mixture. The surplus gasoline supplied to the engine considerably increases the CO and HC emissions. It should also be noted that the cold start emissions from TWC cars are of the same order of magnitude as from cars without catalyst. The increase in cold start emissions is further enhanced at low ambient conditions. The emission regulations used so far in the European Union (EU) are valid in the temperature interval between +20 and +30°C. Since the yearly average temperature in Sweden is about +7°C it is clear that the conditions in the regulation does not reflect the actual driving conditions in Sweden. In the cold climate of Sweden it is very important to decrease the cold start emissions. The cars certified according to the Swedish Environmental Class 1 (EC1) regulation, which is equal to the Californian TLEV limit, have a limit for the CO emissions at –7°C. Cold start emission limits will also be introduced in the EU for the year 2000.

A well-established method of reducing the emissions at cold start is to preheat the engine with an electric engine block heater. Results from tests at Motortestcenter (MTC) of the Swedish Motor Vehicle Inspection Co. have been published by Laveskog et al. [7 – 9]. CO and HC emission reductions of up to 80 % have been measured at cold ambient conditions in these studies. However, the block heater has to be connected to the grid power and must rely on a supply of external energy. The infrastructure for this energy supply only exists to a very limited extent today and is also very expensive to introduce in a large scale. Since the block heater does not work without an external energy supply the emission reductions can only be considered as an upper potential. It is therefore of interest to to develop a technology that is autonomous, i.e. that is working without a connection to the grid power. This is one of the main features of a heat storage.

Some years ago a couple of reports were published covering results from emission test with a heat storage developed by the German inventor Oscar Schatz [10 – 16].

[1] Number in brackets designates references in the reference list at the end of the report.
[2] The regulations do not demand TWC technology but with few exceptions this technology has to be used de to the strict emission levels.

The authors of these reports showed that the system had a potential to significantly reduce the exhaust emissions. Some of the results are shown in chapter 6 in this report. The early prototypes of the Schatz heat storage as well as a commercial heat storage from Modine, which is used by BMW, are based on the principle of storing the heat in a molten salt. Later patents from Schatz, which have been commercialized by the Canadian manufacturer Centaur, use only stored hot cooling water instead of using molten salt. Thermostore is based on similar technology. The main advantage of this technology is the simplified design compared to heat storage with salt.

Even if the main objective of this report has been to report on the exhaust emission results it must be stressed that the main reason for the customers to buy a heat storage, either as an option or as an after-market installation, is not primary the emission reductions. Enhanced driver's comfort is most likely the main reason. A reduction of fuel consumption and emissions are of less importance. However, it may be of interest for some manufacturers to be able to offer an option that reduces the emissions and the fuel consumption instead of increasing them as most of the other options (as climate control etc.). The experience from the marketing by BMW, which for the moment is the only car maker that can offer a heat storage on the Swedish market, shows that the environmental issues play a very small role in the marketing of their product. The cost for the heat storage from BMW is about SEK 10 000. This can be compared with the cost for a fuel heater which is between 10 000 and 20 000 for most cars.

2 BACKGROUND

Thermostore has developed a heat storage based on the technology of storing the coolant fluid in a superinsulated vessel. The basic functions have been proven for a couple of prototype generations that have been tested by installation and vehicle testing.

During June 1997 a couple of emission tests at MTC with the Thermostore heat storage were conducted in order to assess the potential for emission reductions. The tested car was a Ford Taurus, which was a so-called fuel flexible vehicle (FFV[3]). The car was run on gasoline during the tests. The encouraging results obtained convinced Thermostore to publish this report.

The positive results obtained on the Ford Taurus have resulted in the initialization of a new test series with a second car, which is more characteristic for the European and the Swedish market. The car chosen was a Mercedes E 200. The main objective with these tests will be to assess the emission potential in the European driving cycle and by carrying out simultaneous logging of emissions and temperature to obtain valuable insights about how the system should be controlled to fully use the emission potential and to ensure good comfort. The preliminary results are promising and after completion of the test program these results will be published in a new report.

[3] FFV is an abbreviation for Fuel Flexible Vehicle, i.e. a car that can be run on any mixture of gasoline and E85 (85 % ethanol and 15 % gasoline).

3 METHODOLOGY

In this chapter the test equipment, the test objects and the test procedure are described. More information can be found in the emission regulations and in the literature cited which is listed in the reference list at the end of this report.

3.1 Test Equipment

All testing was carried out in Jordbro 20 km south of Stockholm at the facilities of Motortestcenter (MTC), a subsidiary of the Swedish Motor Vehicle inspection Co. The tests were conducted in the test cell number 4 that has the capability to cool the vehicle to a temperature of –15°C (to –20°C in the winter). In this test series temperatures of +22°C and –7°C were used. The air conditioning system has the capability to keep the temperature constant during the entire test, i.e. the cooling capacity is sufficient to handle the heat dissipation (cooling losses) from the vehicle. In the following sections a more thorough description of some of the details of the test equipment is made.

3.1.1 Chassis Dynamometer

The testing was carried out at a chassis dynamometer at MTC. The chassis dynamometer is fully dynamic, i.e. it can simulate an inertia corresponding to the weight of the car. The basic inertia is a flywheel and the rest of the inertia is simulated with the electric dynamometer. Thus the transient conditions such as accelerations and retardations in a driving cycle can be simulated. The inertia for the Ford Taurus was 1700 kg. The chassis dynamometer can also simulate the road load. This load is the sum of the rolling resistance and the air resistance. The settings of the parameters above were made according to the EC regulation.

3.1.2 Measurement of Emissions

The emissions were measured in a dilution tunnel. One reason for using a dilution tunnel is to cool the exhaust gases and the second reason is to obtain a constant flow. The procedure is described in the US Federal Register and in the Swedish emission regulations [17]. A partial flow of the diluted exhaust gases was collected in Tedlar bags for subsequent emission analysis.

The emission instrument used for measurement of gaseous emissions was an instrument from Horiba 9000 series. The particulate emissions were collected after dilution on a Teflon coated filter (Pallflex) and was weighed on a balance with an accuracy of 1 microgram.

The emission components analyzed and the corresponding measurement principles are shown in Table 1.

Table 1: *Emission components and analysis methods*

Emission component	Analysis method
Total hydrocarbons, HC	Heated Flame Ionization Detector (FID)
Carbon monoxide, CO	Non Dispersive Infrared Spectroscopy (NDIR)
Oxides of nitrogen, NO_X	Chemiluminescence (CLA)
Carbon dioxide, CO_2	Non Dispersive Infrared Spectroscopy (NDIR)
Fuel consumption, FC	Carbon balance[4]
Particulate emissions	Gravimetric method

3.2 Test Objects

In this section a short description of the test objects is made.

3.2.1 Test Car

The test car chosen was a 1997 model year Ford Taurus. A picture of a similar car is shown in Figure 1 to the right.

Figure 1: *Ford Taurus FFV*

Even if the car is quite large it represents the size of cars corresponding to the average size of current cars in Sweden. The engine capacity of 3 liters is however considerably larger than the average size of the corresponding cars from the Swedish manufacturers. Some data for the car and the engine is shown in Table 2.

Table 2: *Data for the Ford Taurus FFV*

Parameter	Data	Unit
Car maker	Ford	- - -
Model	Taurus	- - -
Model year	1997	
Odometer	10 100	km
Inertia[5]	1700	kg
Engine family	1F1-S3,0 F2EA-95	- - -
Cylinder capacity	3	dm^3
Certification	94/12/EC & Mk1	- - -
Emission control[6]	TWC, EGR, CAN	- - -

[4] Exhaust gas analysis of CO_2, HC and CO is used to calculate the fuel consumption (knowing the H/C ratio of the fuel)
[5] Inertia corresponds to the vehicle weight that is simulated on the chassis dynamometer
[6] TWC: Three Way Catalyst, EGR: Exhaust Gas Recirculation and CAN: Carbon Canister (used to adsorb the fuel vapors from the fuel tank).

3.2.2 *Heat Storage*

The Thermostore heat storage is of the type where the energy is stored in the hot cooling water only. This technology is also called “sensible” heat storage. Other methods are the molten salt type, so-called “latent” heat storage, and the “thermochemical” storage, which stores the energy chemically.

The Thermostore heat storage comprises a superinsulated cylinder where the cooling fluid is stored, valves, connectors and an electronic control unit. Inside the cylinder a piston separates hot and cold fluid. When the storage is discharged or charged the piston travels between the two ends of the cylinder. One special feature of the storage is the excellent separation between the hot and cold fluid, which not only minimizes the losses, but also makes an intermittent use of part of the stored heat possible. All the different possibilities with the heat storage have not yet been investigated thoroughly enough to chose the best control strategy. An appropriate size of the heat storage is about the same volume as the cooling water volume in the engine block or a somewhat larger volume.

The heat storage can be installed basically in two different positions – under the hood or in the luggage compartment. In Figure 2 the installation of the heat storage under the hood is shown on a Mercedes E 200.

The total weight for the heat storage in the Mercedes is 11 kg. As a comparison the weight of a normal battery of 60 Ah is about 20 kg. In the Mercedes it is possible to install the heat storage either between the radiator and the engine or under the front bumper. The first position was used for the car in the picture since a good access to the storage was of great importance on the prototype to be tested. The second position would most likely be better for practical reasons since the heat storage normally does not need any maintenance.

In the Ford Taurus the heat storage was installed in the luggage compartment, mainly since the space under the hood was limited. The volume of this storage was 9 liters. For the Mercedes a size of 7 liters was used and it was possible to install it under the hood. An installation as close to the engine as possible is advantageous since the heat losses are lower and the heating will be faster. Thermostore has investigated possible installations on 15 common car models on the market and found that the heat storage could be installed under the hood in 8 of them. It has also been found that there are alternative positions (under the hood) on many cars. A normal coolant volume on a medium size 4-cylinder car is about 4 liters. Since the heat storage can be manufactured in different sizes the volume can be adapted to the space and needs in the particular case. It is also possible to install the heat storage in a vertical position under the hood on some cars. Furthermore, the possibilities to make an oval shape have been investigated and it has been found that this is a feasible solution. It is also important to note for future work that the best installation can be made if the heat storage can be integrated already in the design phase of the car.

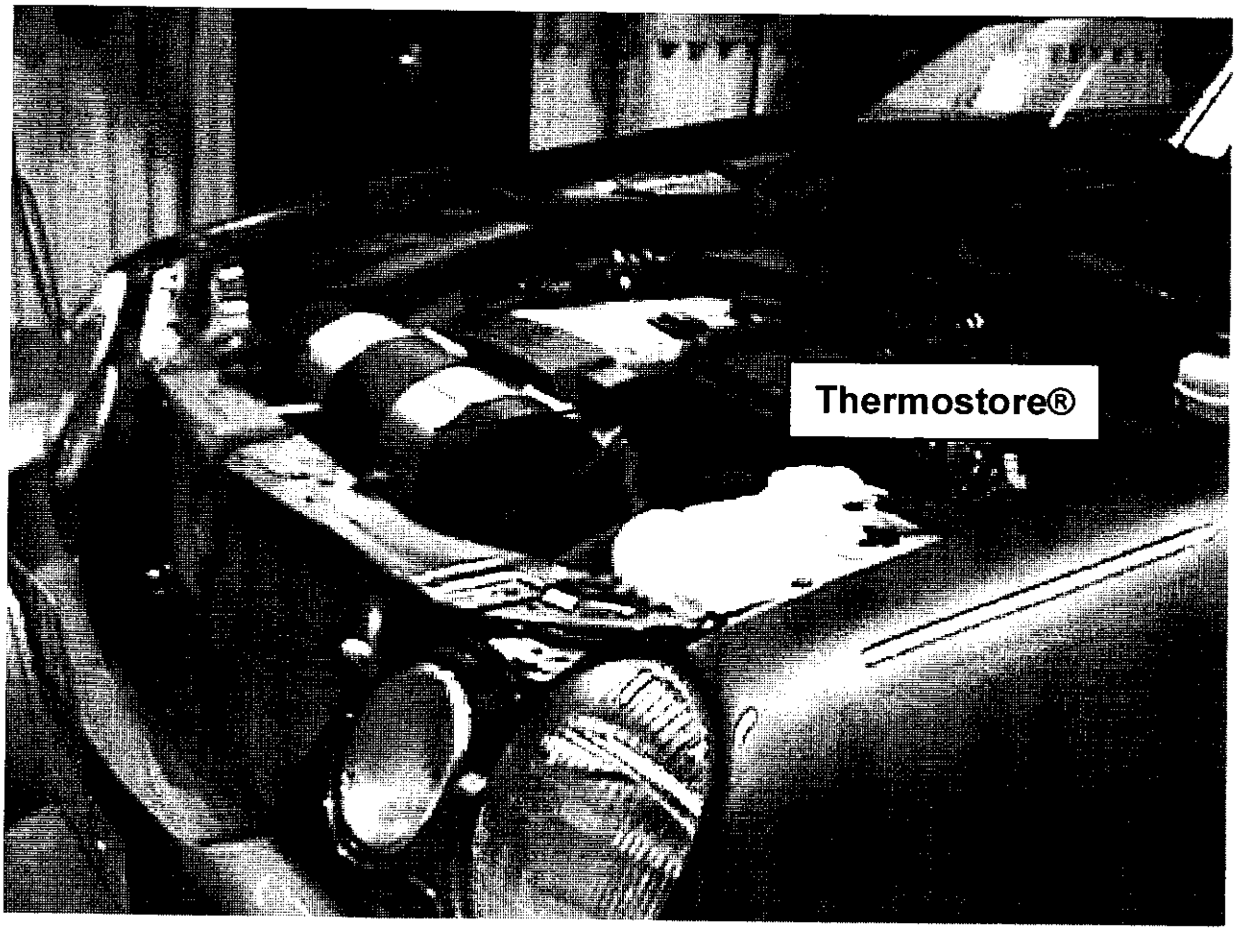


Figure 2: *Installation of Thermostore in the test car, side view*

3.2.3 Electric Engine Block Heater

The electric engine block heater tested had a power of 550 W. The block heater was mounted in the water jacket through a hole in the engine block. The preheat time was 1,5 hours according to the recommendations in a recent report published by the Swedish Consumer Agency [18].

It has been shown in earlier work at MTC that block heaters significantly can reduce the exhaust emissions and it was therefore decided to compare the heat storage with a block heater in this respect.

3.3 Driving Cycle

The driving cycle chosen for the test series was the new European driving cycle (NEDC) to be used after the year 2000 in the European Union. The driving cycle is shown in Figure 3.

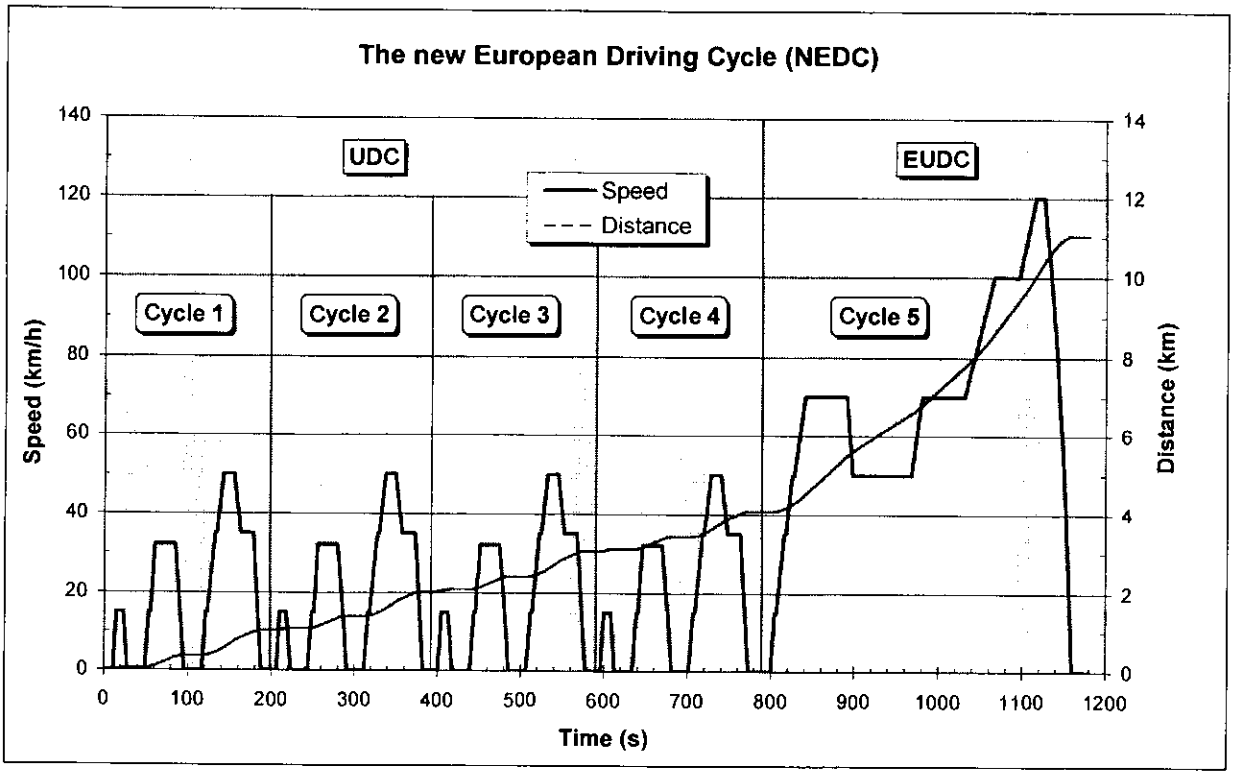


Figure 3: *The new European driving cycle (NEDC)*

In the driving cycle used so far in the EU the engine is first started and then run on idle for 40 seconds before the sampling of exhaust emissions is started. Thus these emissions will not be measured and taken into account in the calculation of the total cycle emissions. The driving cycle will be changed in the Euro 3 regulation for the year 2000. The modification is that the idle phase is omitted and therefore the start of the engine and the start of sampling are simultaneous. The car chosen for the test series had been certified according to the present emission regulation. The reason for selecting the new driving cycle after all was that it was of interest to measure the emissions during the whole start-up phase since this is more realistic.

As a comparison the American FTP-75 driving cycle used in the US and Californian emission regulations is shown in Figure 4. Some of the emission data cited in this report have been generated in this driving cycle. It is obvious that there is a considerable difference between the driving cycles. Furthermore, the FTP-75 driving cycle use weighting factors for each phase of the cycle whereas the European cycle has no weighting factors. In summary it is not possible to directly compare results generated in the two driving cycles.

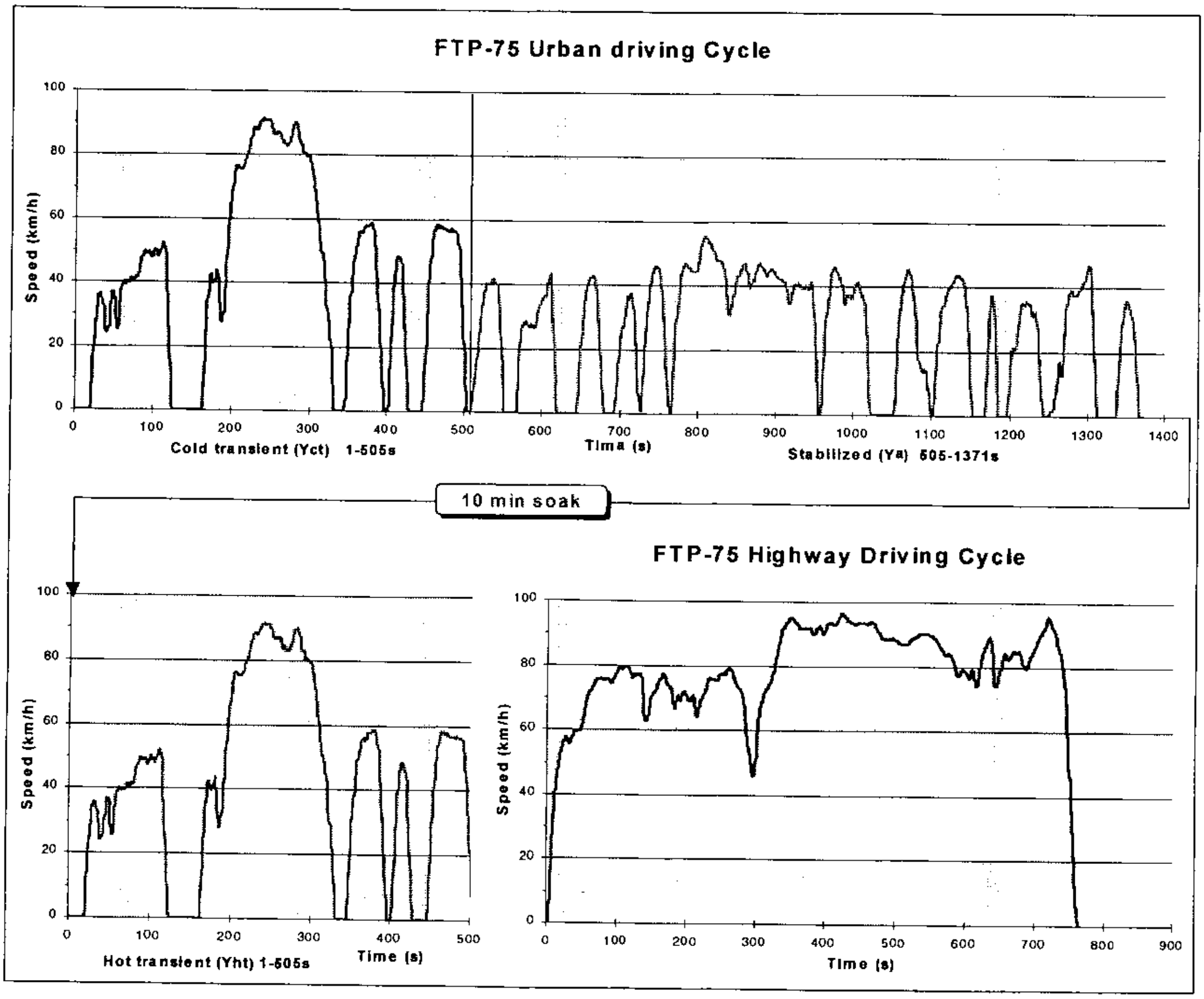


***Figure 4**: The FTP-75 driving cycle*

3.4 Test Program

The test program is listed in the scheme below.

Conditioning in the NEDC-cycle, the heat store is not connected.

NEDC without block heater and Thermostore, +22°C

NEDC without block heater and Thermostore, -7°C

NEDC with block heater 1,5 hours preheat, -7°C

NEDC with Thermostore, no preheat, -7°C

NEDC with Thermostore, 40 seconds preheat, -7°C

NEDC with Thermostore, 80 seconds preheat, -7°C

NEDC with Thermostore, 2 minutes preheat, -7°C

It is worth noting that the first point in the scheme is not a test run but is used only for conditioning of the vehicle. Between the tests the car was allowed to cool down to the test temperature for at least 12 hours. One criterion was that the temperature in the oil sump should be within +/- 1°C of the intended test temperature.

4 RESULTS

The emission results for CO, HC and NO_X for the Ford Taurus are shown in Figure 5.

A general feature of this car is the very low NO_X emissions. The increase in NO_X emissions due to preheating is therefore of minor importance. The NO_X emissions are not affected negatively by a low ambient temperature as the other emissions. For example the CO emissions increase by a factor of 10 and the HC emissions by a factor of 5 when the temperature is decreased from +22°C to –7°C.

As can be seen in Figure 5, the CO and HC emissions can be reduced considerably with a block heater. Thermostore without preheat has higher CO emissions and somewhat higher HC emissions in comparison to a block heater. A preheat time of 2 minutes with Thermostore reduces the emissions further to a level below the level of a block heater. Thus a level of the same magnitude as with an ambient temperature of +22°C can be achieved. From these tests the conclusion can be made that an optimum control strategy for preheating can give very low emissions but also that even without preheating, Thermostore can give significant reductions of the emissions.

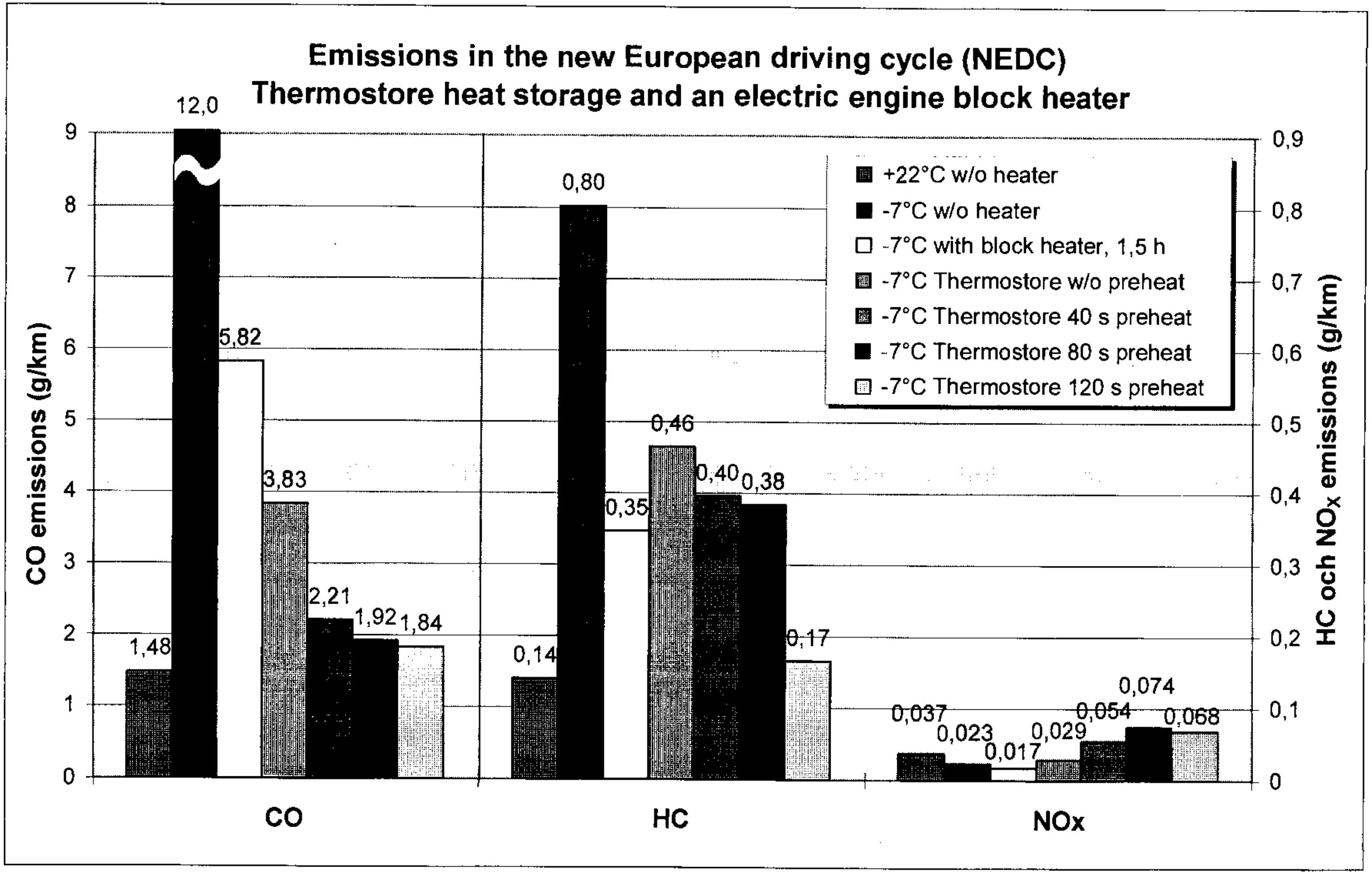


Figure 5: *Emissions in the NEDC cycle*

In Figure 6 the reduction of emissions is shown for the regulated emissions and the particulate emissions by using a block heater and Thermostore (with the best control strategy). In the Figure a sum of HC and NO_X emissions has been shown which is used in the current EU regulations.

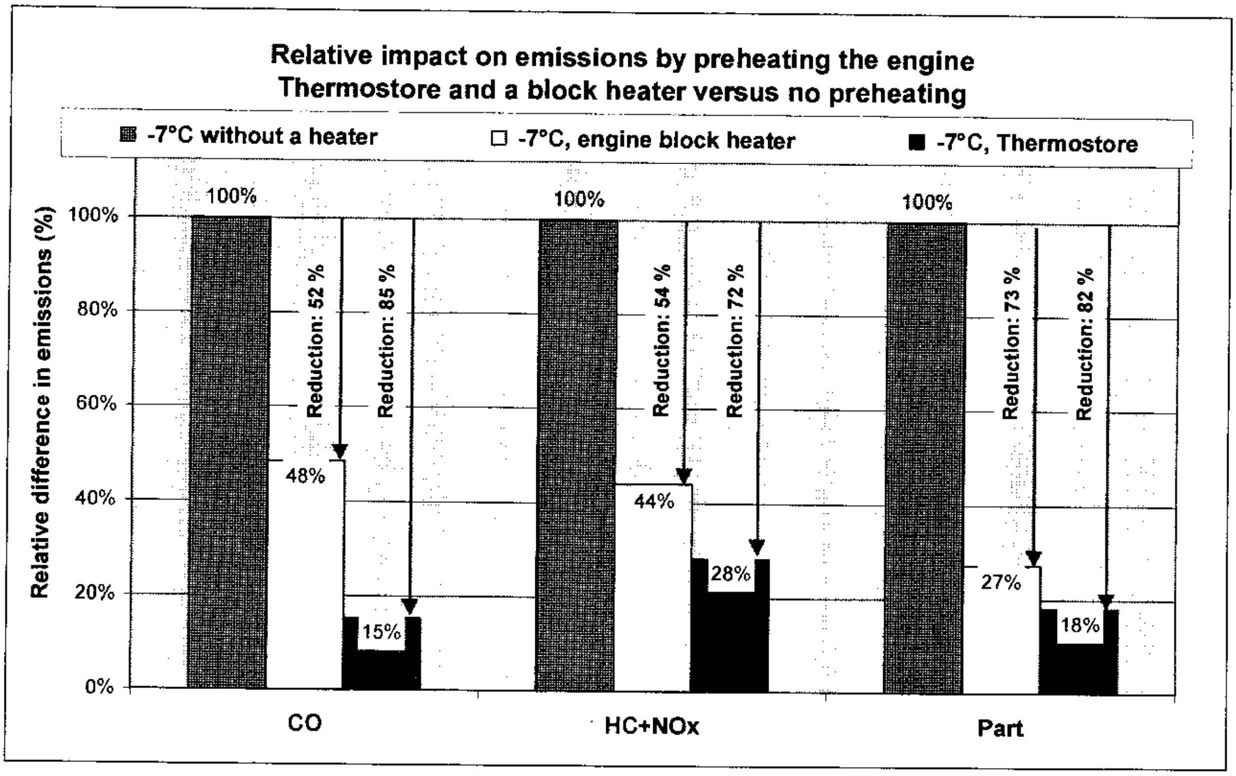


Figure 6: *Summary of the emission potential with different preheating*

In the Figures 7 and 8 the particulate emissions for the Ford Taurus FFV are shown. In both Figures the particulate emissions for the whole cycle have been shown. Since the particulate emissions for a gasoline fueled car is greatest during the cold start phase and after that they are very low, the common practice is to show these emissions in the first phase only in the FTP-75 driving cycle [19, 20].

As can be seen in Figure 7 the particulate emissions increase significantly when the ambient temperature is decreased and if no heating is used. Without preheating and with a short preheating the particulate emissions with Thermostore are higher than with a block heater. With the longest preheating the level is lower with Thermostore and this level is of the same magnitude as at +22°C. It is also worth noting that the particulate emissions are highest during the first two km driven, and that the contribution to the total emissions from this phase totally dominates the cycle emissions.

Figure 8 shows the influence of preheat time on the particulate emissions. The shape of the curve implies that longer preheating than 2 minutes might give even lower particulate emissions. The question is if a simple strategy for the control system can be achieved in a practical way and if this control strategy can be in conflict with the driver's comfort.

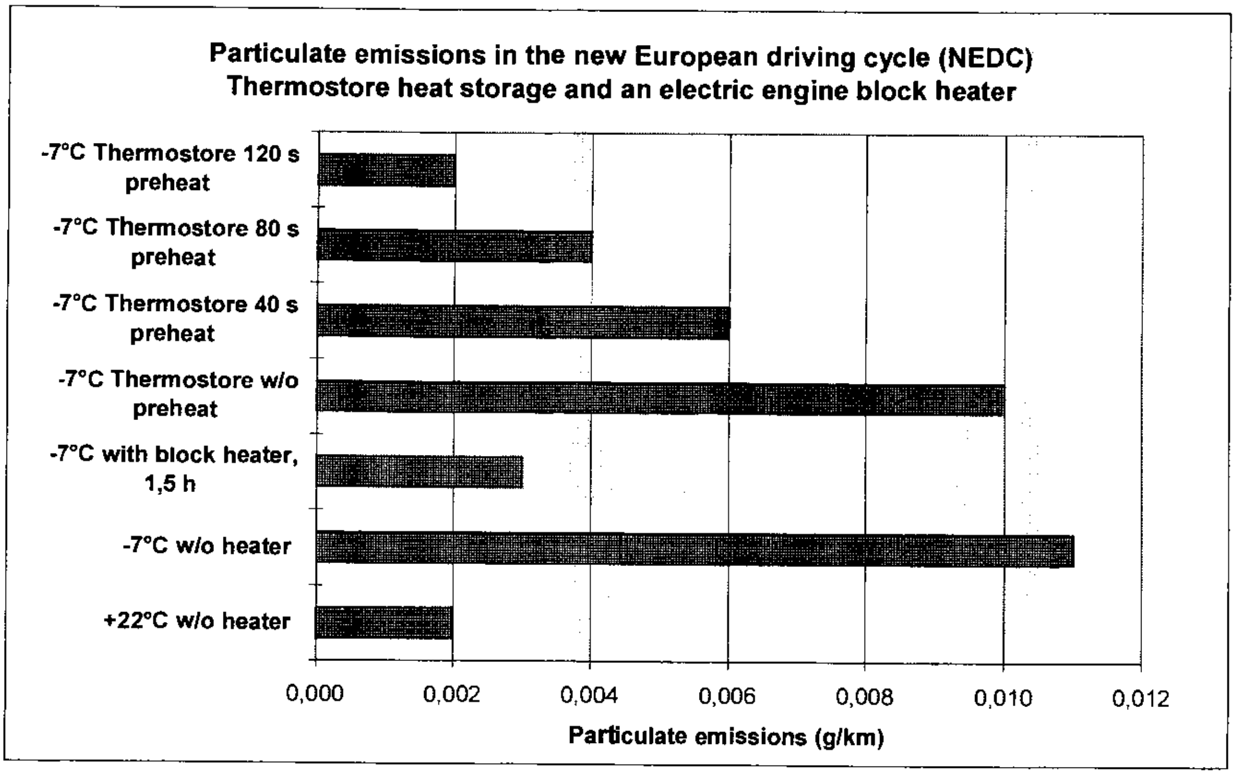


Figure 7: *Particulate emissions*

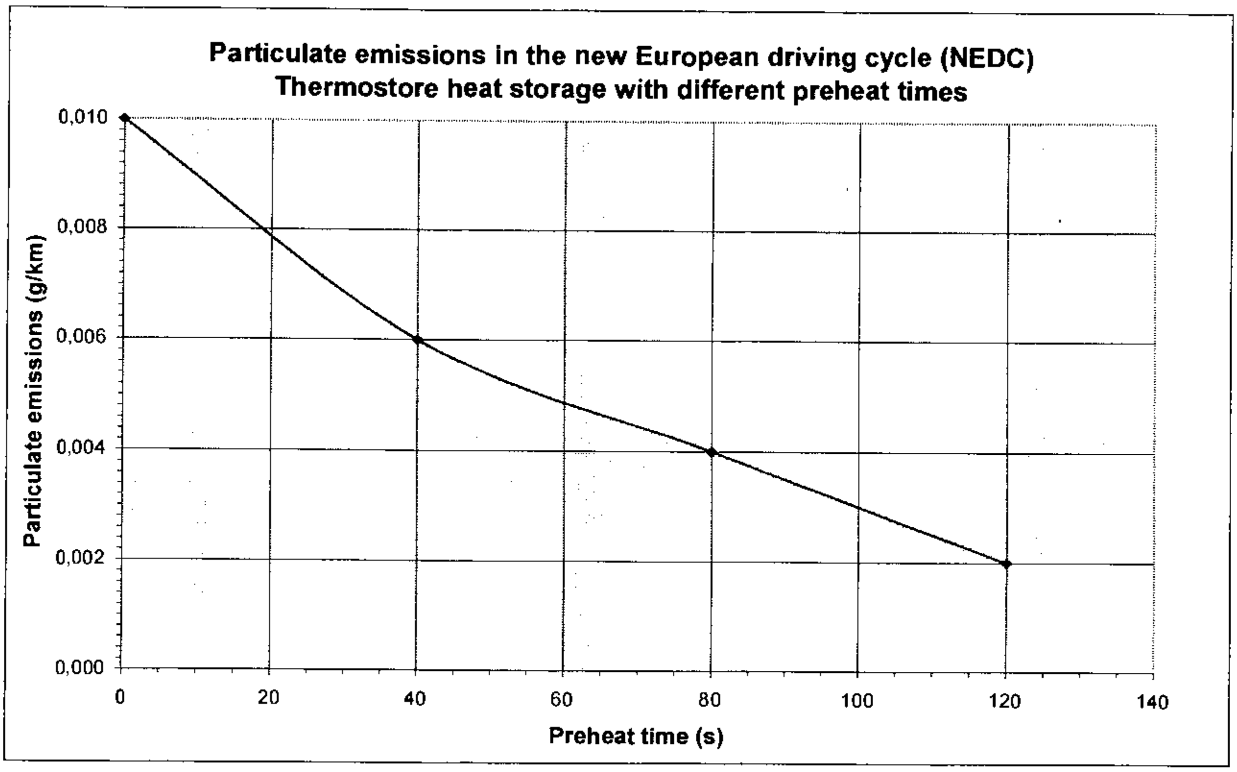


Figure 8: *Particulate emissions with different preheat times*

The influence on fuel consumption is shown in Figures 9 and 10.

A cold start has, as previously has been pointed out, a significant influence on the fuel consumption. Since the complete car is cooled down to the ambient temperature used in the test there are no possibilities to get the same fuel consumption at –7°C as at +22°C solely by heating the engine. Nevertheless, heating the engine significantly reduces the fuel consumption. Without preheating Thermostore reduces the fuel consumption somewhat less than a block heater but with the longest preheat time the gain is larger. As with the particulate emissions, Thermostore shows a monotonically decreasing trend with preheat time and here an even lower consumption can be presumed with a longer preheat time.

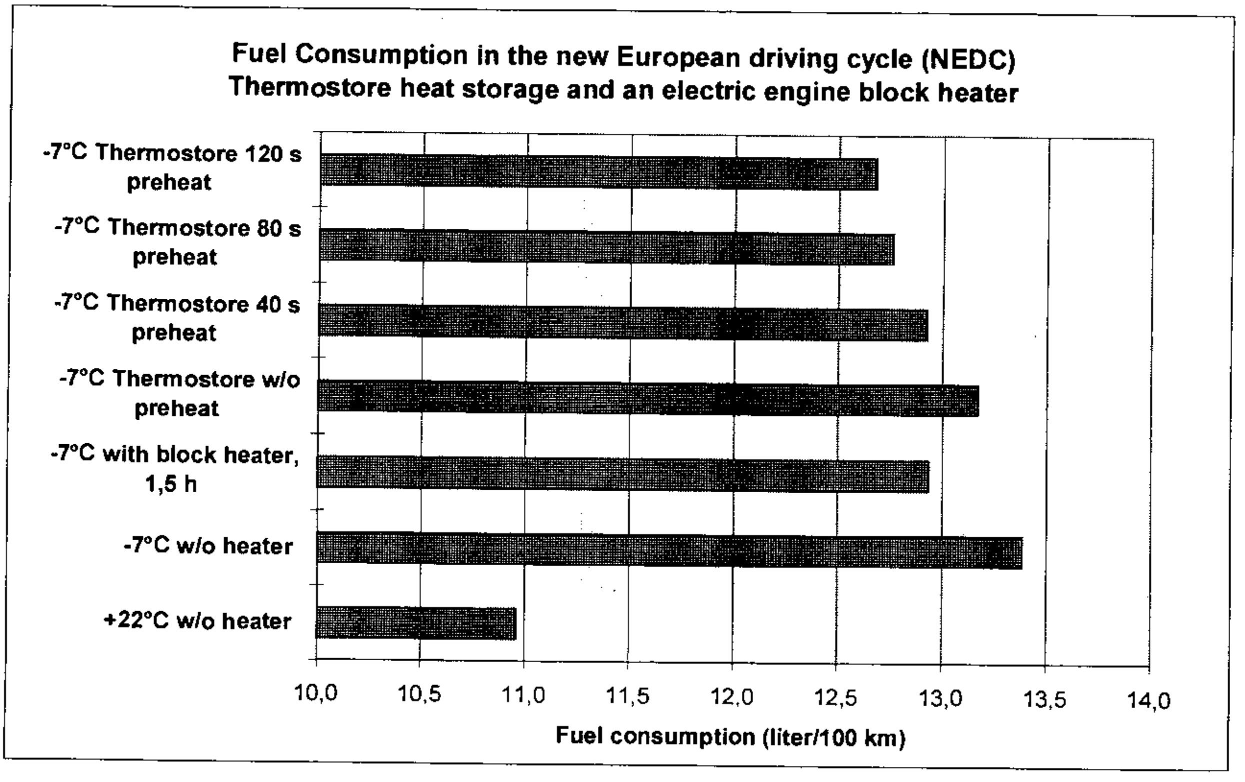


Figure 9: *Fuel consumption*

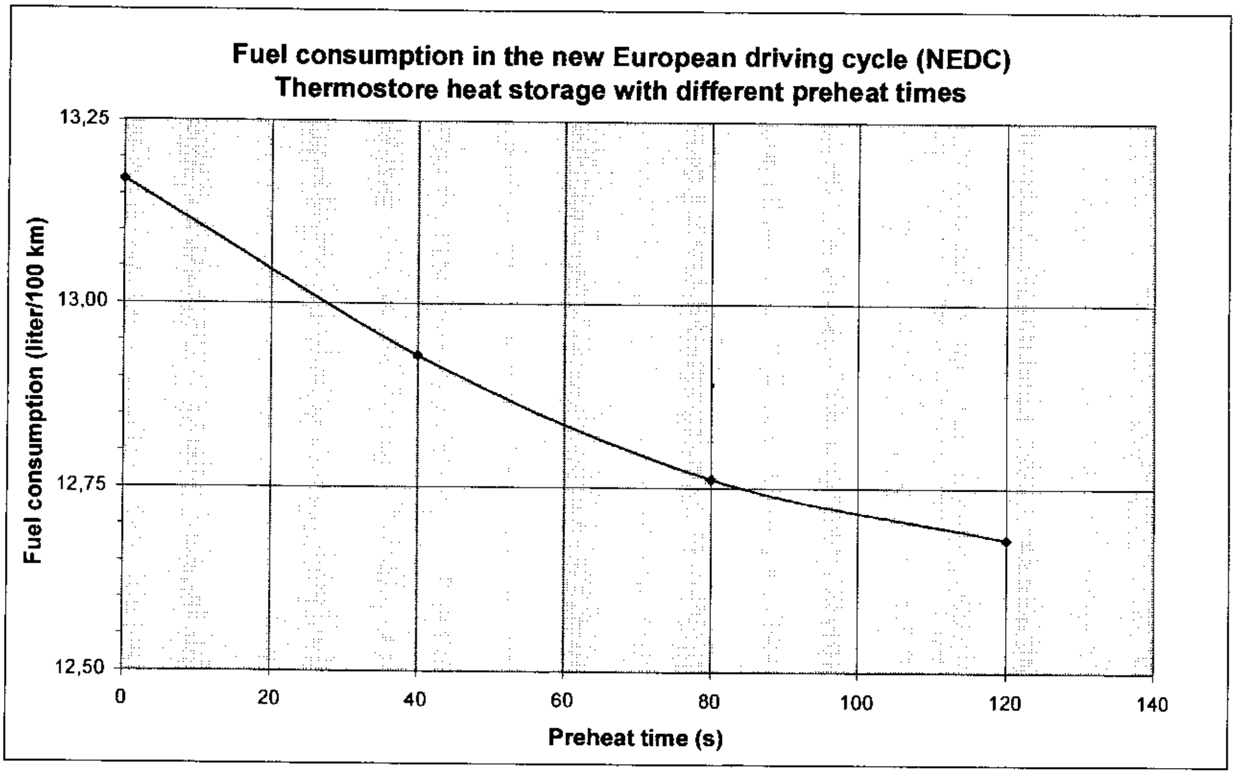


Figure 10: *Fuel consumption with different preheat times*

In order to investigate the preheat time by using Thermostore a simple logging of some temperatures in the engine and in the heat storage was carried out. As an example some results are shown in Figure 11 from a test when 80 seconds of preheat was used. After a few seconds the temperature from the heat storage increased to almost 80°C and to over 70°C at the water pump. The temperature in the cylinder head increased to +20°C but it decreased momentarily again when the hot water mixed with water from sections of the engine block where the water was colder. To obtain more insight in how the preheating is fulfilled and how this affects the emissions simultaneous logging of temperatures as well as the emissions will be carried out in the on-going project on the Mercedes E 200.

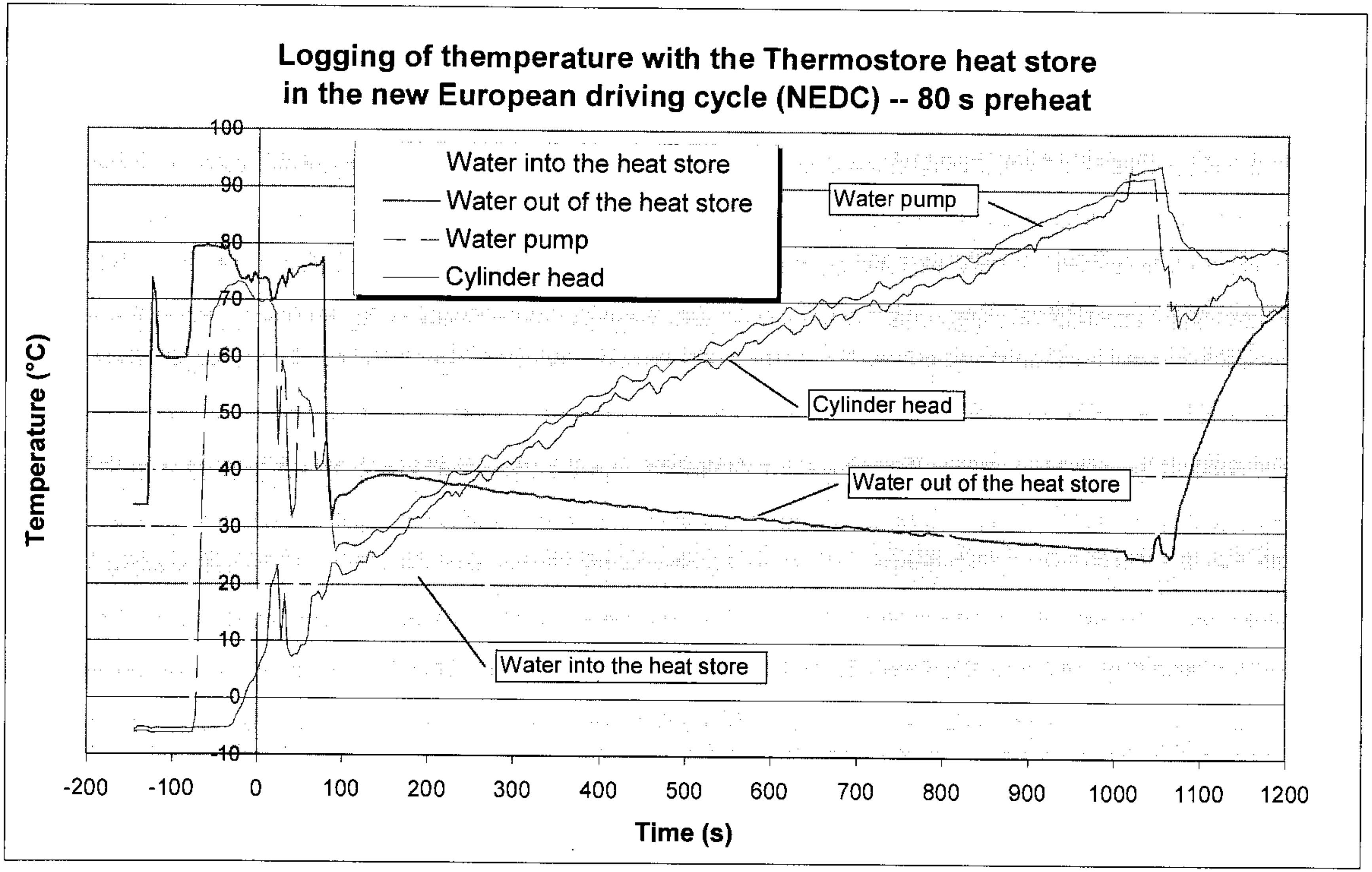


Figure 11: *Temperature logging at +22°C with Thermostore, 80 s preheat*

5 COMPARISON WITH OTHER METHODS TO PREHEAT THE ENGINE

There are some alternative heat storages and other solutions that have a significant potential to reduce the emissions and to increase the driver's comfort. In this chapter a brief overview of these alternatives and their features is made.

5.1 Electric Engine Block Heater with Electricity Supplied from the Grid

Electric engine block heaters have been tested in a couple of projects at MTC. Most of the tests have however, been carried out in the US FTP-75 driving cycle and it is therefore not possible to directly compare the results with the tests in this project since the NEDC cycle was used in our case. In a report from MTC by this author [21] a SAAB 9000 Ecopower was tested with and without a block heater at –7°C. This car was the first car on the Swedish market to have a block heater as a standard equipment directly from the manufacturer. In Figure 12 some of the results from this test series are shown.

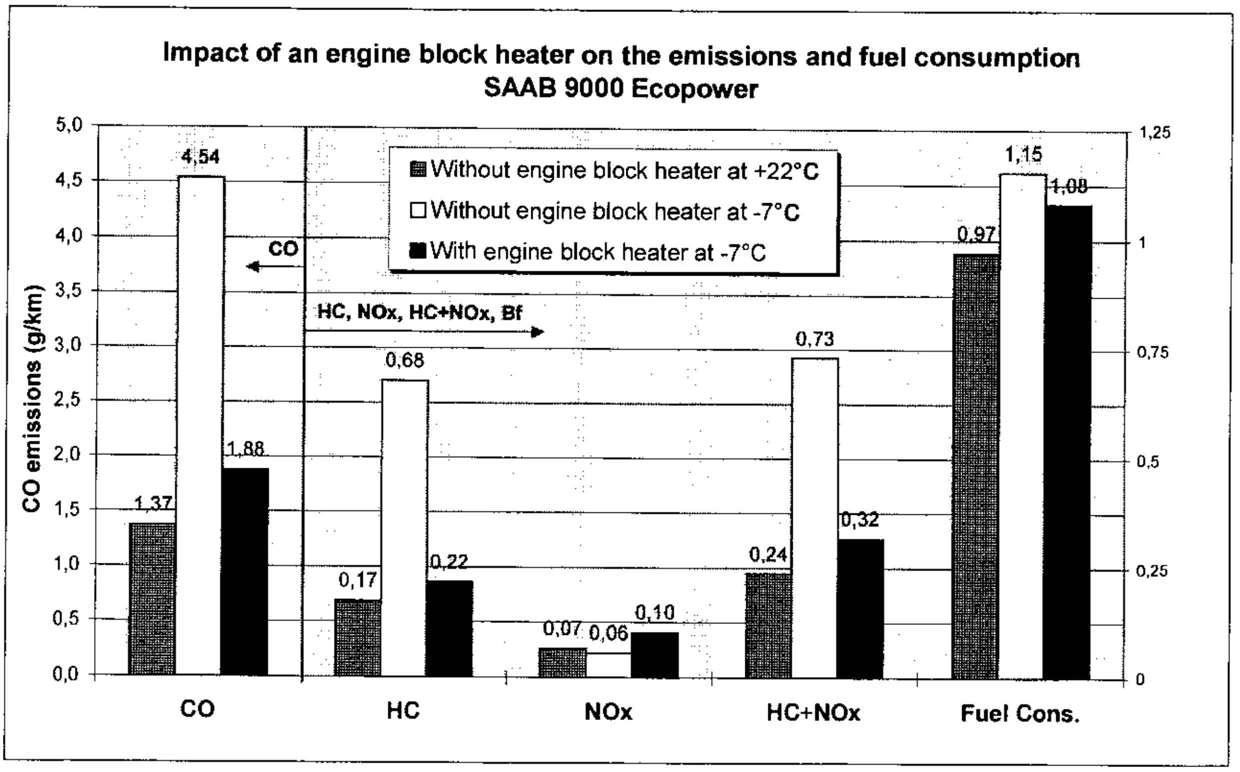


Figure 12: *Emissions from a SAAB Ecopower with and without an engine block heater*

The influence of a block heater on the emissions from this car was similar to the results shown on the Ford Taurus. Unfortunately the particulate emissions were not measured on the SAAB. The fuel consumption was reduced by almost 0,1 liter per start. By using energy from the grid the total energy consumption was higher than in the case without a block heater. Even if later reports have shown that the preheat time can be somewhat reduced there is an obvious risk for an increase in the total energy consumption [18]. It is also of significant importance how the electric energy is produced. If an electric compartment heater is used as well, the total energy consumption will further increase.

The influence on some unregulated emissions have been investigated in a project at MTC on a Volvo 850 car [22]. It was shown that the impact by using a block heater was greater for the unregulated emissions than for HC and particulate emissions. The same trend can be expected with other types of preheating devices as for example the Thermostore.

5.2 Electric Engine Block Heater with Electricity Supplied from the Battery

Some new ideas have been presented about preheating the engine with electricity supplied from the battery in the car. This device could be very simple and inexpensive. It is thus of interest to make some simple calculations to assess the feasibility of this type of heater.

A heater recently commercialized is produced in two power levels of 150 and 240 W respectively. This is significantly less than for a normal block heater, which has a power of 550 W. The preheat time recommended by the manufacturer is 2 hours in the first case and 1 hour in the second case. If the battery voltage is not considerably affected, the energy supplied to the engine will be 300 and 240 Wh respectively. This can be compared to a conventional block heater that supplies 825 Wh of energy during 1,5 hours. The achievable increase in temperature with a heater of this kind is significantly less than with a conventional block heater. The gain in emissions and comfort will most likely be less as a consequence of that. When the energy consumption is of concern another problem arise, and this is the recharging of the battery. Unfortunately an alternator for a passenger car has a very low efficiency – peak efficiencies of about 50 % is not uncommon. In a realistic driving cycle this efficiency can be halved since much of the driving is outside the optimum area in the load and speed map. Furthermore, the average gasoline engine efficiency in a driving cycle is usually between 15 and 20 % – in extreme cases as low as 10 %. Recharging of the battery will therefore increase the fuel consumption more than the heating of the engine reduces it.

5.3 Other Types of Heat Storages

The German inventor Oskar Schatz has patented a system for storing the energy in a molten salt ("heat battery"). In a report from the US EPA[7] the advantages at cold start was demonstrated. Some of the results are shown in Figure 13.

[7] EPA: Environmental Protection Agency

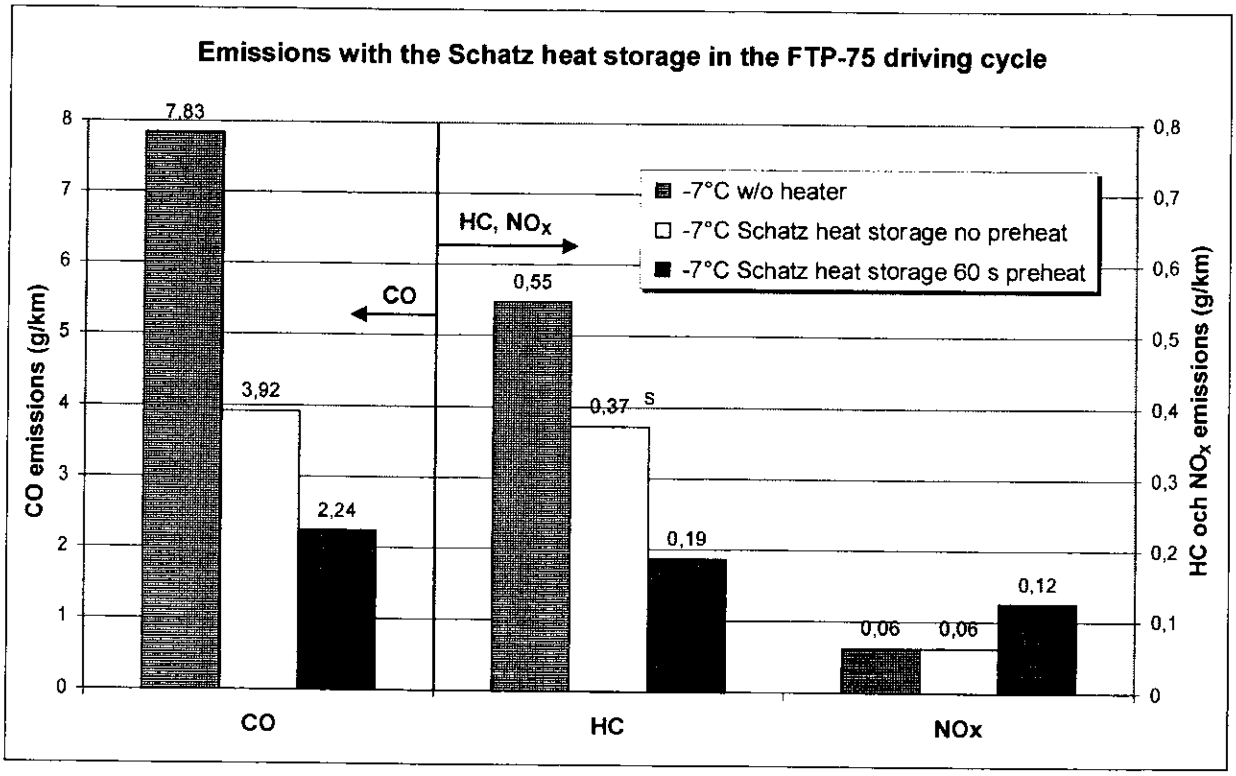


Figure 13: *Emissions with the Schatz heat storage*

Figure 13 shows that the heat battery has a significant influence on CO and HC emissions. At the same time is also clear that preheating is an effective measure to further decrease the emissions. Since the tests were conducted according to the FTP-75 driving cycle the emission levels cannot be directly compared to the levels from the European driving cycle.

Recently Oskar Schatz has developed a new type of heat storage, called Schatz B. This heat storage is (as well as Thermostore) based on storing the hot cooling water. To separate the hot and cold water a labyrinth of sheets creating laminar flow is used. The separation in Thermostore should however, be better due to the sealing piston. The manufacturing rights (non-exclusive license) have been granted to the Canadian Company Centaur, which now is manufacturing the product. Some emission results from the brochure of Centaur are shown in Figure 14. As in the former case the results are from the FTP-75 driving cycle.

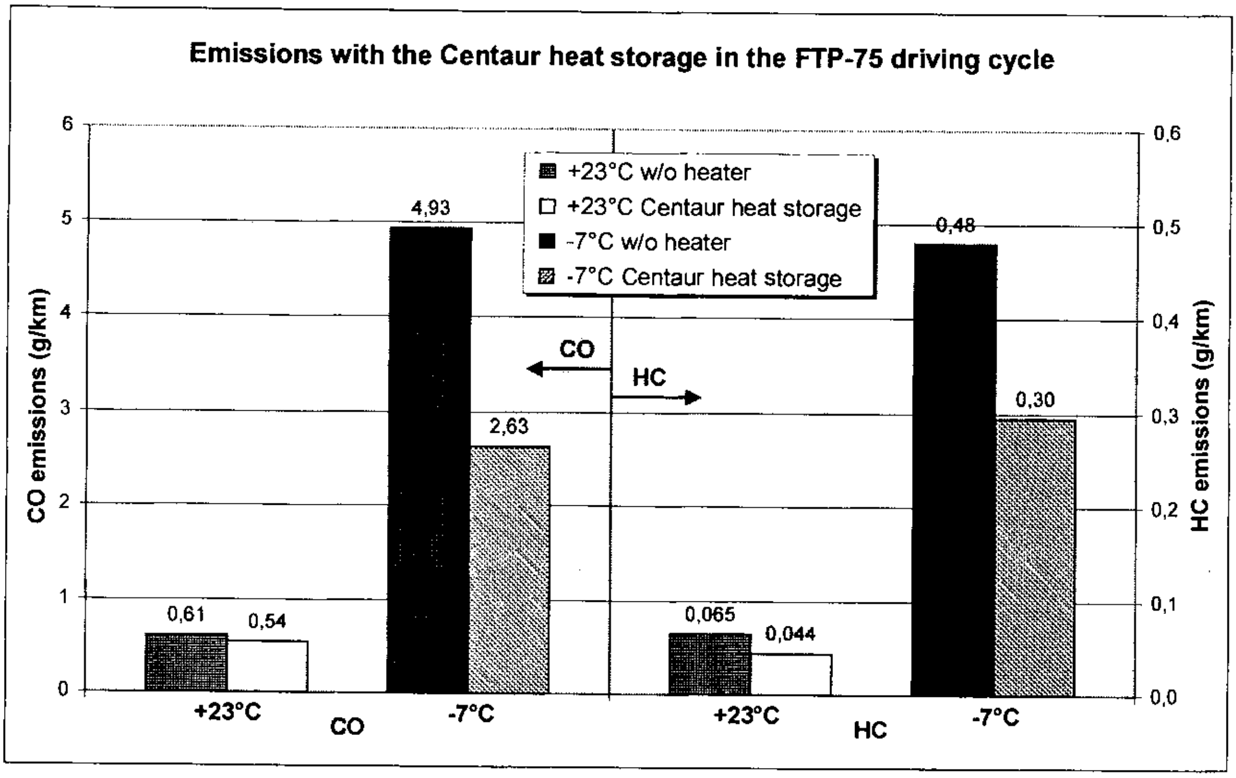


Figure 14: *Emissions with the Centaur heat storage*

The reduction of CO emissions is somewhat less than with the Schatz heat battery shown above but the reduction of HC emissions is of the same order of magnitude. According to the information from Centaur preheating is not used. It is interesting to note that there is a slight advantage by using the heat storage at +23°C as well.

BMW is the only car manufacturer that for the moment is marketing a heat storage on the Swedish market. The heat storage is of the molten salt type and it is manufactured by Modine and Längerer & Reich. The working principle has extensively been explained in two papers in the German Journals ATZ and MTZ [23, 24]. In the latter paper, reductions of CO and HC emissions by 30 and 25 % respectively is stated for the FTP-75 driving cycle. Information from the BMW dealer claims a CO reduction of 43 %. No information is given about the car model or the driving cycle. It can be assumed that the car model is the latest version of the BMW 5-series.

5.4 Fuel Heater

The use of a fuel heater is a well-known method to preheat an engine. Even if no test results that show the emission potential have been found in the literature survey by this author, it is likely that these heaters have similar effects on the emissions as the heaters mentioned before. There are of course additional emissions generated by the heater but there is some scope of keeping those emissions on a very low level. On the contrary, it is more difficult obtain a positive energy balance since the fuel heater usually consumes about 0,2 – 0,3 liters per start and the reduction of the fuel consumption for the car should be about 0,1 liter.

The main problem for the fuel heater is apparently the cost. Depending on the model and version the cost is between SEK 10 000 and 25 000. In spite of the high cost, fuel heaters are installed due to the enhanced comfort provided.

6 DISCUSSION

It is clear from the data generated on the Ford Taurus that Thermostore has a remarkable potential of reducing the exhaust emissions. By using an optimized strategy for the control system there are possibilities of reducing the emissions more than with an electric engine block heater. It must also be noted that a block heater is totally dependent on external energy supply. Studies at the Swedish Road and Transport Research Institute (VTI), cited in reference [18][8], have shown that a block heater is used only in a small fraction of the cold starts. A heat storage, on the contrary, can be used in almost every start, except when the car has been parked for more than a week. Due to the frequent use of the heat storage the emission reductions will be greater than for a block heater. Studies have also shown that block heaters are connected much longer than necessary, thus much energy is wasted. A heat storage has a considerable advantage in this respect.

The literature survey has shown that there are other heat storages than Thermostore that also have a great potential of reducing the emissions. A critical question is whether Thermostore has any unique features that the other heat storages do not have. Due to the distinct separation of the hot and cold water in Thermostore new possibilities emerge to control the heating of the engine. These possibilities have not yet been fully exploited and a lot of optimization work still has to be done to take full advantage of all the degrees of freedom. It can also be noted that the commercial heat storages are not controlled in an optimum way regarding the emissions. In spite of promising tests with preheating, these possibilities are not used today.

A heat storage actually does not compete very much with a block heater, since the heat storage has other capabilities. The main competitor is instead the fuel heater. Since the cost of a heat storage presumably is much lower than for a fuel heater there is a good opportunity to compete. The possibilities for Thermostore to compete with other heat storages will most likely be determined by the cost as well. A simple assessment of the design shows no reason why Thermostore should be more expensive than the main competitor from Centaur. Thermostore should likewise be considerably less expensive than a heat storage based on molten salt.

7 CONCLUSIONS

A heat storage from Thermostore has been tested concerning the influence on the exhaust emissions. The following conclusions can be made:

- Thermostore can significantly reduce the CO, HC and particulate emissions at cold start. At an ambient temperature of –7°C the reduction can be as significant as 80 %.

[8] The complete report from VTI was not available when this report was written.

- Based on tests with a block heater at MTC, one can assume that the reduction of the emission compounds posing health hazards will be ever greater than the reductions of HC and particulate emissions.
- NO_X emissions are not much affected on the test car even if there was a small increase.
- With the best control strategy, Thermostore can reduce the emissions *more* than a conventional electric engine block heater. Furthermore, the improvement is greater than for other types of heat storages.
- With a well-optimized control strategy it should be possible to reduce the emissions even more. However, a certain compromise between comfort and emissions has to be made. The commercially available heat storages are not controlled to obtain the best emission reduction but are optimized solely for the best comfort.
- The test series conducted in this study will be completed with tests on a Mercedes E 200. As a complement to the emission measurements a simultaneous real-time logging of both emissions and temperatures will be made to increase the understanding of how the heat storage is working. The insights obtained can later be used to further develop the product.

8 OUTLOOK

The investigations conducted in this project, in combination with a literature survey, show that it should be possible to optimize the control strategy of the Thermostore. At the same time it should be stressed that the commercially available products have not been optimized in this area. Thermostore has, due to its design features, considerable advantages in this respect. Further gains can be anticipated if the control unit in the car is programmed to take full advantage of the use of Thermostore. The final solution would be to integrate the control of Thermostore in the engine control unit. To realize this, the car industry and their suppliers have to be involved in the development process of Thermostore.

In order to further develop the product, combinations of Thermostore and electric preheating as well as a fuel heater are possible. A cooperation with partners from these branches of industry is necessary in this respect.

There are also other possibilities to further enhance the performance of a heat storage. One such possibility would be to increase the coolant temperature. Some experience from Formula 1, where the coolant temperature has been raised to 150°C is very encouraging. A further advantage of raising the coolant temperature is a reduction of the size of the cooling system. Another trend that could be exploited is if electrically driven water pumps will be used on engines in order to get a better management of the engine temperature and thus the parasitic losses. New opportunities will arise to integrate the operation of a heat storage under such circumstances.

In summary it can be concluded that there are many areas where the product can be further developed.

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